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Regional Variation in Arterial Saturation and Oxygen Delivery during Venoarterial Extracorporeal Membrane Oxygenation

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Abstract: Venoarterial extracorporeal membrane oxygenation (VA-ECMO) can be lifesaving in patients with cardiopulmonary collapse. However, observation studies have implied that oxygenated blood does not pass in a retrograde fashion from the VA-ECMO circuit to the aortic root and arch when the femoral artery (FA) is used. This study aims at accurately measuring the oxygen saturation in various arteries during VA-ECMO through different cannula sites. A total of 20 patients with VA-ECMO were in the study. Fourteen patients had FA cannulation, two patients received axillary arterial (AA) cannulation, and four patients received cannulation of the ascending aorta. Oxygen saturation was measured simultaneously in the radial artery and oxygenator outlet. In the patient group with FA cannulation, the oxygen saturation was lower in the radial artery (97%) when compared with the oxygenator outlet (>99%). In the subset group of patients with severe lung dysfunction, oxygen saturation was even lower in the radial artery (73% saturation). In the patient group with AA cannulation, the oxygen saturation and partial oxygen pressure (PO_2) in the oxygenator outlet and radial artery were similar (99% or greater). In the patient group with direct ascending aorta cannulation, the oxygen saturation and PO_2 in the oxygenator outlet and radial artery were similar as well. Regional variations occur in the blood oxygen saturation depending on the site of the arterial cannulation in patients with VA-ECMO. With FA cannulation, the oxygen saturation in the radial artery is significantly lower than the one in the oxygenator outlet. This may imply that the coronaries and the brain receive hypoxic blood from the left ventricle. These results suggest that antegrade cannulation for VA-ECMO improves oxygen delivery to the proximal aorta distribution. **Keywords:** VA-ECMO, arterial oxygen saturation. *JECT. 2013;45:183–186*

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) can provide lifesaving cardiopulmonary circulatory assistance in patients with refractory cardiogenic shock. It can be initiated quickly when necessary through various access routes including retrograde femoral, axillary, and direct central cannulation. All approaches offer full cardiopulmonary bypass and support. However, central and antegrade (axillary) cannulation provides flow in a more physiologic direction and manner than retrograde (femoral) cannulation and flow. In the former, the coronary and cerebral circulations are the first to receive oxygenated blood, whereas with the latter, they receive oxygenated blood later in the course of flow.

An additional physiologic consideration is that the patient's native cardiopulmonary circulation is often at least partially functional during ECMO support. Despite accurate cannula placement, patients will have flow through the right heart and across the lungs with left ventricular ejection. In these circumstances, there is likely mixing of native and ECMO flow of blood with unclear effects on end-organ saturations. This has been demonstrated in earlier animal studies (1–5).

Our curiosity was raised after managing a patient admitted for recent cardiogenic shock. The patient was a 65-year-old, 90-kg man with left anterior descending artery

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stent placement 5 months prior. The patient had been transferred from a nearby hospital after cardiac arrest. The patient was intubated and an intra-aortic balloon pump was inserted. Arterial blood gases revealed worsening acidosis and hypoxia. Echocardiogram identified poor biventricular function with a left ventricular ejection fraction of 15%. Radiographic images showed whitening of the lungs. A decision was made to initiate VA-ECMO. A 25-French Biomedicus multiport cannula was placed in the femoral vein (Medtronic, Minneapolis, MN). A 19-French Biomedicus percutaneous cannula was inserted into the femoral artery. For distal limb perfusion, a 5-French Pinnacle cannula was used (Terumo Medical, Elkton, MD). The ECMO circuit consisted of a Centrimag pump (Thoratec Corp., Pleasanton, CA), a hollow-fiber oxygenator (Maquet Corp., Rastatt, Germany), and a coated tubing circuit. After uneventful transition onto ECMO, the patient appeared stable. The ECMO settings were 4.0 L per minute gas flow at 100% FiO_2 with a blood flow of 4.8 L per minute and 4200 RPMs. The ventilator was set at a rate of 10 breaths per minute with a tidal volume of 200 mL at percent oxygen (FiO_2) of 70%. A blood gas from right radial artery at 1 hour revealed a pH of 7.37, pCO_2 39 mmHg, pO_2 298 mmHg, and arterial oxygen (O_2) saturation of 100%. The oxygenator outlet sample was similar. Within 6 hours of initiation of ECMO, the arterial saturation (%) measured from the right radial artery dropped to 70% despite an oxygenator outlet pO_2 of 519 mmHg and 100% saturation. This could not be improved with either changes in ventilator settings or blood flow. The arterial return cannula was later moved to the axillary artery position with improvement in proximal blood gases and a favorable patient outcome.

With these physiologic issues of this patient in mind, we sought to determine if there are regional variations in O_2 saturation and delivery based on cannulation site in a series of patients with varying degrees of residual native cardiopulmonary function. This study aims at accurately measuring the arterial O_2 saturation in various arteries during VA-ECMO when different sites for the arterial outflow cannula are used. Implications of this can be significant because adequate cerebral and coronary oxygenation is vital for appropriate functional recovery.

METHODS

After permission from the Institutional Review Board of our institution, records of 20 patients with VA-ECMO were retrospectively reviewed. Procedures performed from April 2011 through December 2012 were included. The patients were divided into three groups based on the site of the aortic inflow cannula position: Group 1 received femoral arterial cannulation, Group 2 received axillary arterial cannulation, and Group 3 received direct cannulation of the ascending aorta through median sternotomy. Oxygen saturation and partial oxygen pressure (PO_2) were measured in the blood of the radial and femoral arteries at various ECMO flows. The initiation blender settings for all ECMOs were set at 100% and 1:1 gas flow ratio. The FiO_2 was then adjusted to achieve a PO_2 of greater than 100 mmHg. The target pump flow was set at an index of at least 2.0–2.4 L per minute per meter^2 with RPMs adjusted as necessary to meet this target. Additional adjustments were made by volume resuscitation and cannula adjustment as necessary to achieve adequate flows. The hematocrit target was 30%.

All the patients received the same VA-ECMO circuit. This consists of a centrifugal blood pump (CentriMag; Thoratec Corp.), a Quadrox-D oxygenator (Maquet Corp.), and a coated tubing circuit (Terumo Corp.). The total system prime was 465 mL. For peripherally cannulated patients, the venous drainage cannulae consisted of the percutaneous Medtronics (Minneapolis, MN) Multi-stage Femoral venous kits, sizes 19 French to 25 French. The arterial return cannula were the percutaneous Medtronics One-Piece Femoral arterial kits, sizes 15–19 French. Specific cannula selection was guided by patient size and femoral vascular dimensions. Antegrade femoral arterial perfusion cannulation was used in all patients to avoid leg ischemia. This consisted of ipsilateral 5–6 French sheath with y-connection from the systemic femoral arterial cannula.

When central cannulation was performed, our standard Terumo 21-French Soft-flo was used for arterial return. For venous drainage, a 31-French Right Angle Medtronics DLP in the right atrium was used. For axillary cannulation, an 8-mm graft was interposed onto the vessel and a Terumo Softflo cannula was inserted and tied into position.

Ventilator management followed a low-volume, low-pressure strategy with tidal volumes of 4–8 mL/kg body weight and peak pressures of less than 30 cm H_2O. Fi*O2* was held at nontoxic levels ranging from 35% to 50% as needed.

Simultaneous blood samples were drawn from a pigtail off of the oxygenator outlet and the right radial artery. Data values were compared using Student's *t* test. *p* values listed as $< .05$ imply a significant difference.

RESULTS

All 20 patients were adults (68% males) and had an average age of 59 years (standard deviation = 10) who developed cardiopulmonary failure necessitating VA-ECMO (Table 1). The device was inserted either at the bedside through the percutaneous technique or in the hybrid operating room through the open technique. Group 1 was the largest group and consisted of 14 patients, whereas Group 2

Table 1. Patient demographics.

Group	Age (years)	Weight (kg)	Male (%)
1	59	74	55
1_{Subset}	60	69	40
2	61	73	100
3	60	69	75

consisted of two patients and Group 3 had four patients. Average duration of ECMO support was 8 days.

The various O_2 saturations of the blood in the radial and femoral artery in the three groups are shown in Table 2. Differences were noted in the retrograde cannulated group with femoral artery cannulation. Although all patients in this group demonstrated decreased radial artery saturations, the most striking differences were in patients with severe lung injury and partial preservation of cardiac output. Patients with severe lung injury had significantly lower O_2 saturation in the radial artery vs. femoral artery samples (73% vs. 99%; p value < .001). Increases in ventilator FIO_2 settings had minimal effect on radial saturations in those patients. There were no differences in regional arterial saturations in the antegrade cannulation group.

DISCUSSION

The effect of VA-ECMO on O_2 saturation in the various parts of the body can be significant in determining the outcome in critically ill patients with cardiopulmonary failure. Although previous laboratory studies have suggested this, cannulation position remains an area that has not received full attention from the medical and surgical community. In particular, O_2 saturation differences between the radial and femoral arteries during VA-ECMO have not been extensively studied to determine the degree of oxygenation of the blood that the aortic arch receives with possible dramatic effects in end organs like the brain and the heart through the coronary arteries.

Table 2. Oxygen saturation difference between radial and femoral samples with antegrade vs. retrograde cannulation during ECMO.

		Radial	Femoral	p Value
Retrograde	Group 1, N = 9	97%	99%	NS
	N = 5, severe respiratory $failure_{subset}$	73%	99%	< .001
Antegrade	Group 2, N = 4	99%	99%	NS
	Group 3, N = 2	99%	99%	NS

ECMO, extracorporeal membrane oxygenation; Group 1, femoral cannulation; Group 2, axillary artery cannulation; Group 3, central (aortic) cannulation; NS, nonsignificant.

More than a decade ago, Kato et al. (2) studied the coronary arterial perfusion in puppies during VA-ECMO. The results demonstrated that even during high ECMO flows in the femoral artery, the oxygenated blood did not pass in a retrograde fashion into the aortic root. As a result, the coronary arteries received blood of low O_2 concentration with catastrophic effects to the function of the ventricles. The authors concluded that the lack of increase in PO_2 in the ascending aorta with high-flow VA-ECMO means that the coronary arteries were perfused mainly with blood ejected from the left ventricle, because there was no evidence of direct retrograde flow from the VA-ECMO outflow cannula to the coronaries. Other studies have produced similar results (3–6).

Our results show significant variations in the O_2 saturation depending on the site of the arterial cannulation in patients with VA-ECMO. In some cases with femoral arterial cannulation, the PO_2 in the radial artery is significantly lower than in the femoral artery. This may imply that the coronary arteries and the brain receive hypoxic blood as a result of desaturated blood being ejected from the left ventricle or this could be a result of the "last pass" effect of retrograde arterial flow reaching the coronary and cerebral circulations late in its course. This conclusion is further supported by the fact that in patients with obstructive lung disease, the radial artery blood had even lower O_2 levels, suggesting even more dependence on antegrade flow for oxygenation of early antegrade branch vessels.

The least amount of variation in O_2 concentration between the oxygenator outlet and the radial arteries was in patients in whom the outflow cannula was placed in the ascending aorta. This is of no surprise, because it resembles most closely the normal physiology of the blood flow. The ascending aorta cannula is in the most favorable position, because it supplies oxygenated blood almost directly to both the coronary and the carotid arteries. Cannulation of the axillary artery is an alternative antegrade choice. This cannulation, however, is technically more challenging. The importance of this finding lies in the fact that the axillary artery can be cannulated in a much less invasive approach than the ascending aorta, which needs a sternotomy.

A limitation of this study is the small number of patients. However, in addition to previous laboratory studies, these results provide further proof that retrograde flow can result in regional blood flow alterations that lead to both coronary and cerebral ischemia. As a result, more clinical studies in both adult and pediatric patients are needed to address this issue and validate our results. The results from this observational study suggest that alternative approaches to both cerebrovascular monitoring and arterial cannulation should be reviewed. Wong et al. (7) suggest the use of near-infrared spectroscopy to measure cerebral oximetry during ECMO. This technique assists in evaluating transitional changes in O_2 delivery. Alternative cannulation techniques may include the use of a longer femoral arterial cannula similar to a multiport percutaneous venous cannula, a hybrid approach that returns oxygenated blood to the pulmonary artery, and a percutaneous vent catheter that would reduce left ventricular ejection. In our attempt to provide "lung rest" during ECMO, we must remain aware of the potential effects on both cerebral and coronary circulation.

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